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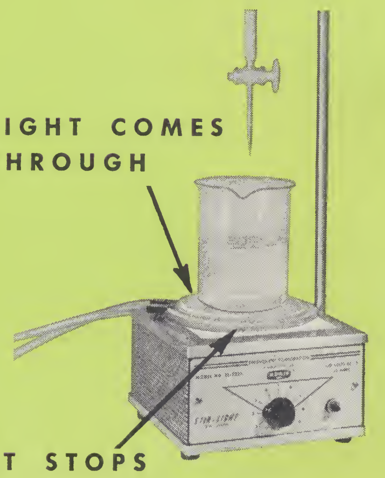

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BULLETIN
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Maximizing The Electric Furnace In The Laboratory

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Thermolyne Corporation

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Editor's Note: For more knowledgeable utilization of available electric furnaces—and for attaining better end results—the author presents an in-depth study of this R & D tool. In this first installment of a two-part article, various designs and controls are discussed.

Electric furnaces and their controls are deceptive in their apparent simplicity. Of course, their complexity isn't as great as many other pieces of laboratory equipment. There are, however, a number of subtle problems involved in design which are not apparent at first sight. A better understanding of these problems will help the furnace user obtain better results and longer life from his equipment.

This discussion will be limited to the more popular sizes and types of furnaces; those units up to about two cu. ft. capacity which use base metal heating elements and attain temperatures up to 1260°C (2300° F). Although these remarks apply primarily to muffle furnaces, they will also apply to tube furnaces of the same temperature range.

A muffle furnace is basically a thermally insulated, heated chamber. Because of its convenience, cleanliness, flexibility in design, and ease of control, electrical heating is undoubtedly the most popular heating medium for the smaller muffle furnaces. This is particularly true of those units designed primarily for laboratories. For the larger industrial furnaces, oil and gas firing are often used.

Heating Elements

Heating elements are the heart of the electric furnace. They may be classed according to the type of resistance material from which they are made: noble metal such as platinum; refractory metal such as molybdenum or tungsten; base-metal alloys of various proportions of iron, nickel, chromium, and aluminum; and the non-metallic substances silicon-carbide and molybdenum-disilicide.

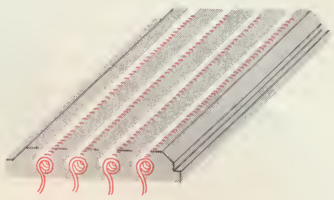
Of the base metal alloys (to which this discussion is confined) there are fundamentally two types: nickel-chromium and iron-chromium-aluminum. The former has been used since the early 1900's for a variety of heating elements; the latter is a more recent development and has since gained wide acceptance in the electric furnace field among others. Although these two materials may at first seem to be entirely competitive, they are to a great degree complementary.

Because the alloying of resistance materials is a highly specialized field, the furnace designer's primary problem is how to make the best use of the alloys developed by a relatively few manufacturers in this field. Thus for a given furnace design, heat must be supplied to the chamber at a given rate. This can be accomplished by using heating-element wire having a small surface area but a large temperature difference between the wire and chamber; or it can be done by using wire having a large surface and a small temperature difference. Because wire life is decreased by approximately 50 per cent for each 50° C temperature rise, the latter method is much preferred.

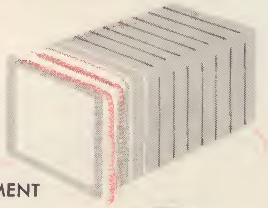
A primary factor determining the element to chamber gradient is the amount of power dissipated per unit surface area of the element wire. To a first approximation, the lower this figure, the lower the gradient. Six to ten watts per square inch represents good design. Values lower than this are difficult to achieve in smaller furnaces without using step-down transformers.

Assuming the use of helical-coil elements (as used in most furnaces of this size), power density can be decreased by winding coils more closely so as to get more wire into the same space, thus increasing the surface area. Because adjacent turns of wire are now closer, any given turn has greater difficulty in radiating its heat, with the effect that the improvement gained by the greater surface is largely nullified. If the exposed area of the heating element itself is at least half (but preferably comparable to) that of the wire it contains, one can be reasonably certain that the individual turns of the coil and the coils themselves are sufficiently spread to permit easy radiation.

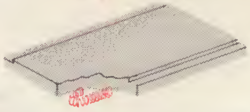
Another major problem of the furnace designer is support of the heating element wire. There are three well-known methods of accomplishing this: open coil construction is perhaps the most popular; muffle core construction is used by at least one major manufacturer; embedded construction, at least with present techniques, is the most recent. Initially embedding utilized a glassy bonded refractory oxide which suffered from softening at higher temperatures; the advent of chemical bonding overcame this difficulty.



OPEN COIL HEATING ELEMENT



MUFFLE CORE HEATING ELEMENT

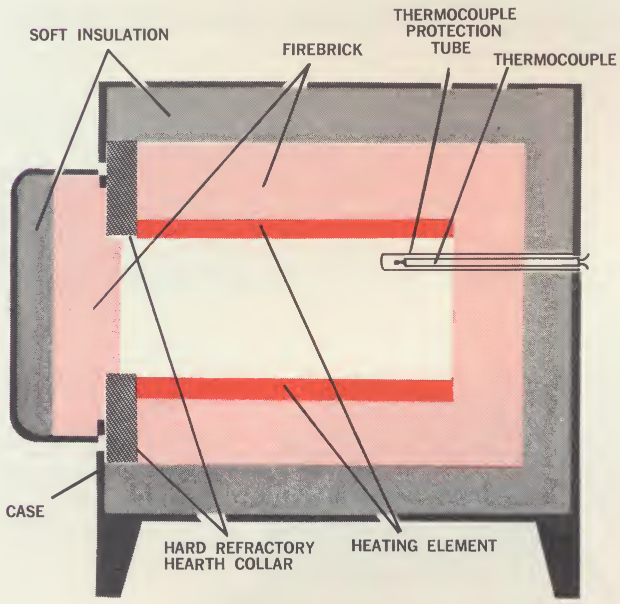


EMBEDDED HEATING ELEMENT

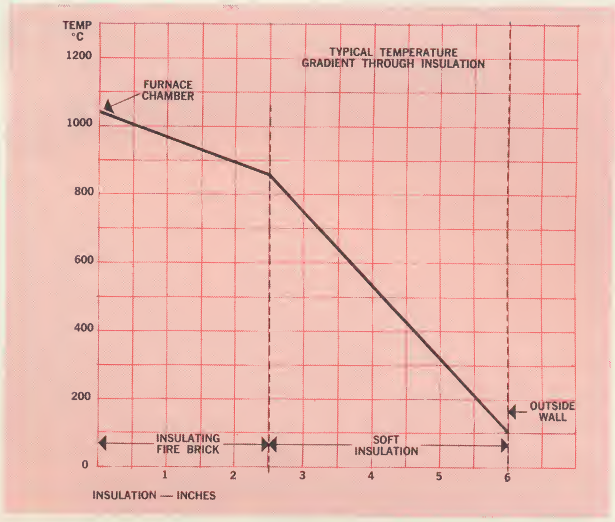
The final "thermally functional" part of the furnace is the insulation. Broadly speaking, there are two types of insulation available to the furnace designer—insulating firebrick and "soft insulation." The former is mechanically durable and is used for the furnace interior which is subject to some abuse; the latter is weak mechanically but has a much higher insulation value than firebrick. Therefore, a combination of the two is used by placing the soft insulation in a position surrounding the firebrick where it is protected from abrasion. Also, in this manner, the soft insulation (which does not have the temperature capability of firebrick) is protected from the extreme temperatures of the furnace interior.

The case of the furnace does not impose any particular design problems. Formed and painted sheet steel provides the best compromise among durability, appearance, and economy. One manufacturer uses a double-shell construction, venting the space between for a cooler surface.

There are many different styles and arrangements of furnace doors, each having certain advantages. If a larger furnace is to be used frequently for small parts, one of the door styles that does not require complete opening for access to small loads will minimize heat loss.



Nomenclature of a muffle furnace



Typical temperature gradient through insulation

Controllers

To control furnace temperature, power input to the furnace must be regulated, and the controller is the basic power-regulating device. However, because most controllers will not carry the full amperage required by the furnace, a contactor (load carrying relay) must also be used.

There are basically two type of controllers: input controllers (open loop) and automatic controllers (closed loop). Input controllers maintain temperature by establishing an equilibrium between the heat losses from the furnace and the power input to the furnace; in other words, for a given input (as established by the control setting) the furnace temperature assumes that value where the heat loss is equal to the input. Typical input controls are variable transformers, variable resistances, clock-driven percentage timers, and constant-input percentage timers which maintain a uniform input regardless of line voltage fluctuations. Although input controls can give very good results if closely supervised, a short period of negligence can result in ruined work or burnout of elements. Experience indicates that furnaces equipped with this type of control burn out elements much more frequently than those equipped with automatic controllers.

Automatic control is undoubtedly the better solution to the control problem for most uses. Almost all automatic controls for the temperature range of interest here are actuated by thermocouples which consist of a pair of wires of dissimilar alloys, and give an output (in the millivolt range) approximately proportional to the temperature difference between the joined and open ends. In order to establish the absolute temperature at the joined ends (hot junction) there must, therefore,

be compensation for the temperature at the open ends (cold junction). This is commonly done by extending the cold junction of the thermocouple to the controller by means of special thermocouple lead or extension wires, and compensating for the cold-junction temperature by circuits or devices in the controller.

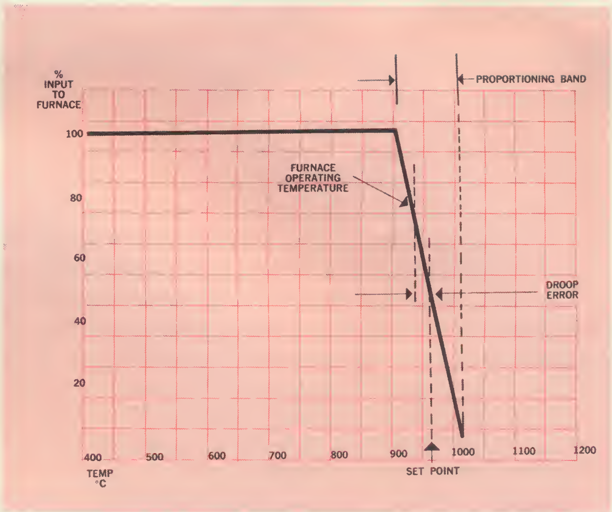
The simplest form of automatic control is the non-proportioning on-off control where heat is supplied to the furnace when the temperature (as measured by the thermocouple) is below the desired or set temperature, and turned off when the temperature is above the set temperature. In furnaces where the thermocouple can immediately sense any change in temperature of the heating elements, this can give very good control. Most furnaces, however, have appreciable lags with the results that the chamber temperature is somewhat "ahead" of the thermocouple. This results in an initial "overshoot" and subsequent oscillation of the temperature about the set point.

To overcome the effects of moderate thermal lags in a furnace a simple proportioning control is usually incorporated. Proportioning gives an input to the furnace which is proportional to the difference between the set temperature and the actual temperature. Thus, for example, a furnace operating with a set temperature of 1000 degrees may have an input of 100 per cent when the temperature is 100 degrees (or more) low, 75 per cent when the temperature is 75 degrees low, 50 per cent at 50 degrees, etc. At the set point then, the furnace is completely off.

It is more practical, however, to design the controller with the set point 50 degrees lower so it is centered in the proportioning band. Furnace input will, therefore, be 100 per cent at 50 degrees low, 75 per cent at 25 degrees low, 50 per cent at the set point, and completely off at 50 degrees above the set point. In actual practice the proportioning band is made somewhat narrower than 100 degrees; 10 to 20 degrees C is typical.

Referring to the above example, suppose we set the controller to 950 degrees and our furnace requires 75 per cent input to hold this temperature. The system will stabilize at a point that will give 75 per cent input, see curve. This is 925 degrees (actually the furnace will require a shade less than 75 per cent input at 925 degrees; this does not materially affect our argument, however). There is, therefore, a 25-degree offset between the set and controlled temperatures. This error is inherent in proportioning controls and is known as droop. With the narrow proportioning band used in most cases, droop error is negligible. For the most precise work, however, its presence should be recognized and compensated.

The most popular form of proportioning control is time proportioning. In this control the power to the furnace is rhythmically pulsed (perhaps once a minute), the average power input being determined by the "duty cycle" — the fraction of the

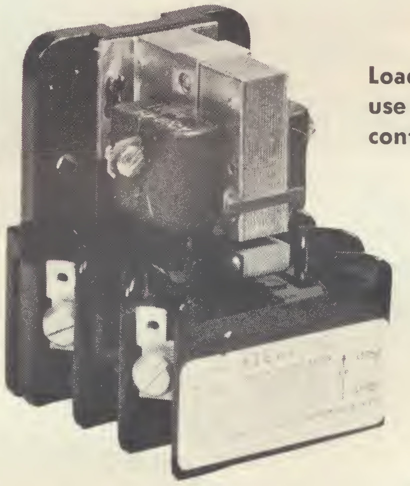


Graphical illustration of proportioning.

total time occupied by the pulses. Although this is the most economical form of proportioning, it does suffer from shortened life of associated relays (as compared with non-proportioning control), especially when furnace and load characteristics are such that a pulse rate of several times a minute is necessary to prevent excessive temperature fluctuation. Shortened relay life for most cases of laboratory usage is unimportant; it becomes a major consideration primarily in those cases of long uninterrupted use of a furnace.

In cases where pulsing gives too much fluctuation or where reliability dictates, continuous or stepless control of power input is used. In past years, saturable reactors were virtually the sole solution to such control; relatively recently, silicon controlled rectifiers have made their debut in this field. Although the latter do not hold any decided operational advantage, space savings and, in many cases, cost savings are appreciable.

In the few instances where droop errors are objectionable and manual correction is undesirable, one must turn to those controllers designed for automatic correction—commonly termed automatic reset. In order to overcome, in turn, an



Load carrying relay for use with temperature controllers.

undesirable result introduced by automatic reset (known as reset wind-up) another feature is introduced—anticipation. Each of these additional features has its own adjustments, and setting for optimum results deserves due consideration.

Perhaps the most important point of the preceding discussion is that furnaces and controls are both parts of a system and any considerations of accuracy should include the system as a whole. In fact, those familiar with servomechanisms will recognize an automatic control and furnace as a servo in which energy transfer in part of the loop is by means of heat. Being a servo, stability or accuracy is determined by the phase shift or lags of the individual components plus the overall gain of the loop. Varying the width of the proportioning band merely varies the loop gain; the narrower the band, the higher the gain. ✦

In this second of a two-part article, parameters to consider in the selection of a laboratory furnace and controller are presented. Installation, factors in the care of elements, and techniques for more accurate results are also covered.

Factors to consider in selection of a controller and furnace are: temperature capability, accuracy, furnace capacity, heat-up time, and recovery time. In addition it may be possible for the potential user to choose heating elements of a material that is most immune to attack from vapors released by substances placed in the furnace.

Temperature capability presents the easiest factor in selection. If operation in the intermittent range of a furnace is considered, it may be helpful to remember that this rating is based on the permissible shortening of element life at higher temperatures (life is approximately halved for every 50 degrees C temperature increase).

Accuracy may be defined as the difference between the temperature of a part placed in the furnace chamber and the temperature for which the controller is set. Because accuracy involves the greatest number of variables, it is the most difficult factor to determine (without actual measurement). The more important of these variables are the following (in approximate order of importance).

1) Temperature gradient in a furnace can amount to 25° to 50° C from the center of the chamber to the door or rear wall. To avoid these extremes, a furnace with sufficient volume or area should be closed so that only the central half to two-thirds of the front-to-rear dimension need be used. Furnaces with heated doors and rear walls have negligible gradient; however, for a given uniform temperature zone, their cost is comparable to a furnace of conventional construction having a similar uniform zone.
2) Controllers carry a rated accuracy of generally from ¼ to 2 per cent, depending upon how close the calibration follows the pubished temperature-millivolt curve for the particular thermocouple. For the millivoltmeter type controllers, deviation from truly perpendicular mounting can materially influence rated accuracy. It might be noted that rated accuracy is determined as a percentage of maximum temperature at any place on the scale. Thus a controller with a range of 1000° C and an accuracy of ½ per cent may be in error by five degrees at any place on the scale.

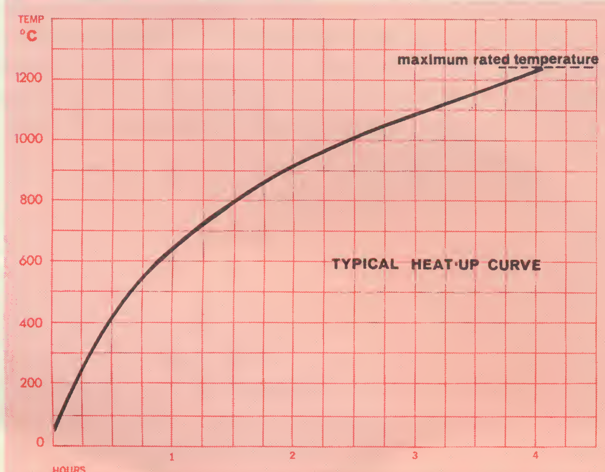


FIGURE 1

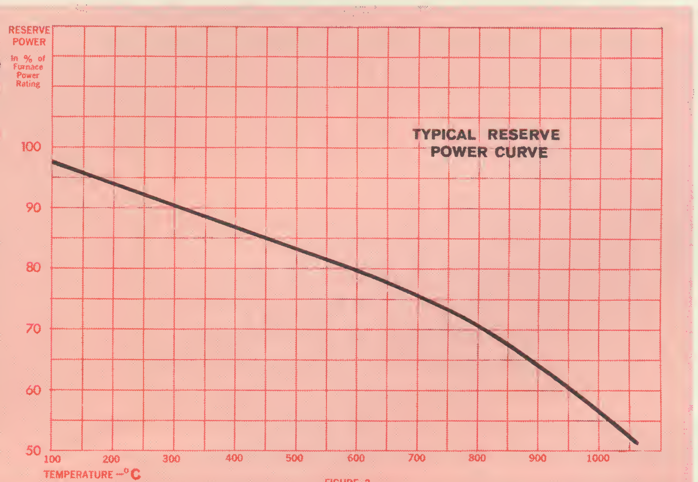
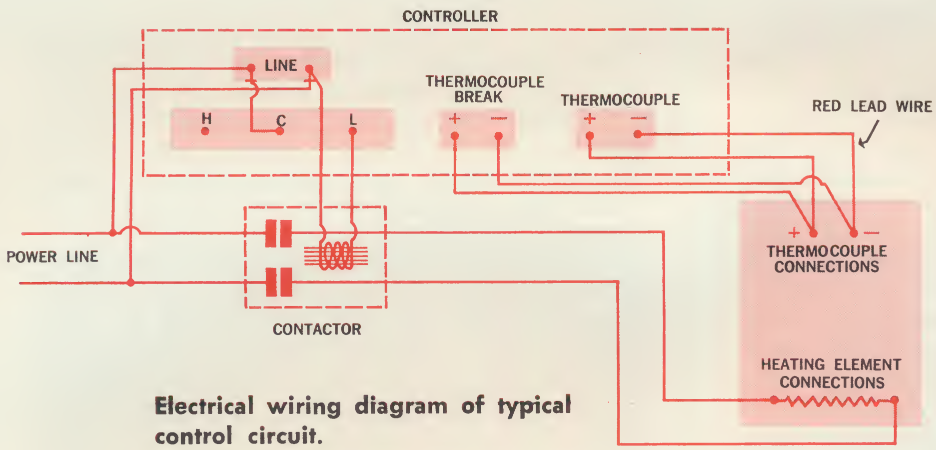


FIGURE 2



Electrical wiring diagram of typical control circuit.

Packaged control which only requires connections to furnace and power line.

3) The two most popular types of thermocouples used in electric furnaces are chromel-alumel (used up to approximately 1200° C) and platinum-platinum 13 per cent rhodium (used at higher temperatures.) Accuracy of chromel-alumel couples is ¾ per cent and platinum couples ½ per cent. Some manufacturers of thermocouples provide somewhat higher accuracy by matching the characteristics of the two wires. Thermocouples have a tendency to drift in calibration when used near their maximum rated temperatures or when contaminated by foreign substances.

4) Droop error was discussed in the previous article. For most purposes it is negligible.

Often, accuracy in itself is not the prime consideration, but repeatability is. This will be discussed subsequently.

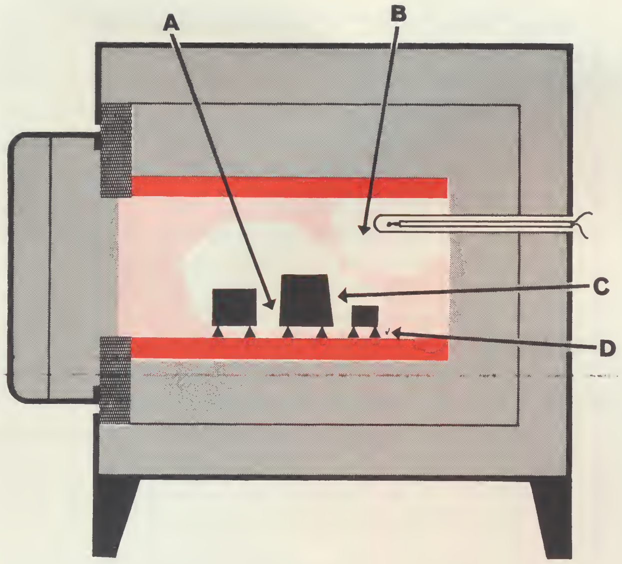
Furnace capacity is largely a function of the desired accuracy. An overloaded furnace can produce some very severe temperature gradients which lead to non-uniform results and sometimes element burnout. For the most accurate work, chamber volume should be of the order of 20 times or more the volume of the load. For less exacting work this ratio may be reduced somewhat; however, there should always remain a space between the load and heating elements through which the heat can circulate. This is particularly true in the region of the thermocouple so the thermocouple will respond rapidly to heat changes. Perhaps the best rule here is: "If in doubt, get the next larger furnace".

Heat-up time, (see curve) may be important in some applications. Manufacturers will furnish data on this parameter to those interested. Heat-up with a load will be, as a first approximation, equal to the time to heat the empty chamber to the desired temperature plus the recovery time of the furnace to that temperature.

Recovery time defines the interval it takes for the furnace to regain the operating temperature after a load has been placed in it. One method of estimating this factor is by using the concept of reserve power (see curve). For example, a furnace having a rated input of 10 kw may require two kw at 600° C to supply heat losses at this temperature; therefore, eight kw of reserve power is available for recovery. Now, if a 10-kg piece of steel (specific heat 0.1) at 0° C is placed in the furnace, it would require 10,000 x 0.1 x 600 calories to heat it. Eight kw is equivalent to 1920 calories per second. Therefore it would require 600,000/1920 or 312 seconds for recovery. This of course, does not necessarily mean that the steel has reached this temperature; it does mean that the furnace will recover in the calculated period even if the steel does soak up enough heat to reach 600 degrees.

Heating element material is another consideration in furnace selection. If the temperature range is above 1100° C, there is not too much choice; most furnaces use iron-chromium-aluminum elements at these temperatures. At temperatures below 1100° C, either iron-chromium-aluminum or nickel-chromium may be used.

Nickel-chromium is generally conceded to be resistant to the widest range of corrosive agents—for example, it is considerably more resistant to alkali halides than iron-chromium-aluminum. There are a few materials, however, to which the latter is more resistant, the best-known being sulphur and its compounds. Therefore contemplated use of either of these materials will largely dictate which elements should be used. Sometimes the only recourse is to try the other if one is not giving satisfactory life.



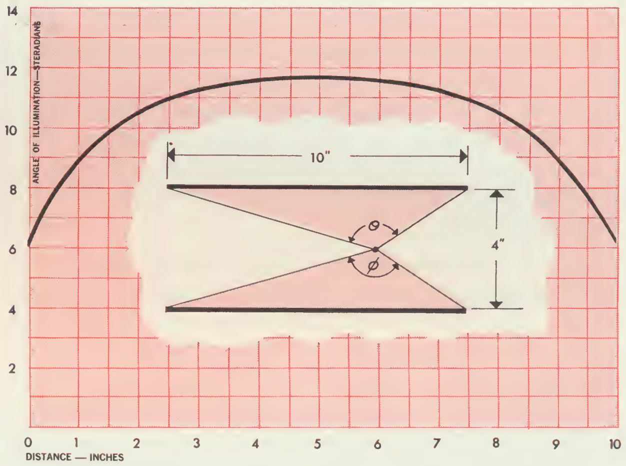
Points to consider in loading a furnace:

A. Provide breathing space between objects.

B. Keep objects (particularly thermal insulators) away from thermocouple.

C. Use central half or two-third of chamber.

D. Block up load with small pieces of ceramic or use hearth plate.



Heat illumination angle ($\Theta + \Phi$) of an object in different positions along the axis of a ten-in. long by four-in. diam. cylindrical furnace chamber. Note relatively uniform central zone.

Available power is a final consideration in choosing a furnace. According to present standards, nominal voltages are 120, 208 and 240 volts. If a "220-volt line" is available, it may either be 208 or 240—voltage should be measured, if in doubt.

Almost all 120-v lines are rated at no more than 20 amperes; therefore either be sure the selected furnace for this voltage has a rating lower than this, or check to see if more amperage might be available.

Higher voltage circuits almost always are rated to at least 30 amperes. It is well to check this also; there are few things more embarrassing than to have a furnace without the power to operate it. It might be mentioned that it is usually possible to operate furnaces designed for 240 volts on 208 volts; heat-up and recovery times will be somewhat longer, however. In the case of operation of controllers on other voltages, it is best to consult the manufacturer.

Installation of Electric Furnaces

Installation of a furnace with most controls is not particular complex—anyone with a general knowledge of electrical wiring should be able to do it. Control wiring is further simplified by packaged control equipment that is now available.

There are two unusual facets to control wiring. Because the thermocouple extension or lead wire is actually a continuation of the thermocouple, it has polarity. Therefore one must be sure the red coded lead is connected to the negative thermocouple terminal at the furnace, and to the negative thermocouple terminal on the controller at the other end. Note that, unlike electronic circuits, red is always negative in coding thermocouple lead wire.

The other peculiar aspect lies in the thermocouple break protection circuit. In some cases a pair of wires from the controller is brought out and connected to the junction between the thermocouple. and thermocouple lead wires. It would appear that the same results could be effected by making this connection within the controller; however, the resistance of the lead wires must be considered. If the connection is not made properly, a considerable temperature error will result.

Loading the Furnace

There is no doubt that an experienced user can obtain better results with good equipment than the novice with excellent equipment. Attention to a few details can make a vast difference.

Undoubtedly the most critical factor in obtaining uniform results is furnace loading. At the risk of sounding facetious, one may say that cooling is the reverse of heating. In other words, the same techniques should be used for heating a load in a furnace as would be used for cooling.To cool a group of small parts fast and uniformly, for example, one would spread them out to permit the heat to escape; similarly, the same method should be used when they are heated so they may absorb heat readily. In addition, sufficient space should be left between the load and heating elements so

that heat from the latter may be radiated easily (and not reflected back); heat confined by reflection will cause hot spots. Use of hearth plates as recommended by the manufacturer will permit heat to be dissipated properly from the bottom element.

Temperature gradient in a furnace is largely a function of the solid angle through which a given position in the furnace receives "heat illumination" directly from the elements. The parts of a furnace where this angle remains a relatively constant fraction of a complete sphere (4π steradians) will be at a uniform temperature. In positions near the door and rear, this angle becomes considerably less, resulting in lower temperatures. Generally speaking, this results in uniform temperatures in the central half to two-thirds of the chamber. For most precise results, the load should be confined to this region.

Element Care

As seen before, there are two basic alloys for heating element wire. Nickel-chromium protects itself from further oxidation by forming a complex nickel-chromium oxide coating; iron chromium-aluminum by an aluminum oxide coating. When one reflects upon how easily most materials completely oxidize at these temperatures it can be realized that development of such alloys is no mean feat. It can be seen also that development of alloys to resist all corrosive materials is virtual ly impossible. Nevertheless nickel-chromium is resistant to a wide range of substances; iron-chromium-aluminum to some which attack nickel-chromium.

There remains, however, a variety of materials to which neither alloy is entirely resistant. It is difficult to anticipate what these are because trace amounts seem to play an important role, and because there are indications that some substances tend to catalyze reactions between others. Perhaps the first thing to do is to try to minimize the attack by preventing spillage (especially if the bottom elements are involved more frequently) and by venting the furnace thoroughly immediately after use. After this has been done and element life is still not satisfactory, one can (by experiment) determine which element material will best withstand the attack of the substances being used. Most manufacturers can supply elements of an alternate material to replace existing elements. In some cases of repeated burnout of the bottom element, use of a hearth plate may give longer life. At times however, shortening of life from chemical attack must be accepted as a normal occurrence—in other words, this is the normal life for the particular operation.

Element life rapidly decreases with temperature increase—wire manufacturers variously give figures ranging from a decrease of one-third to two-thirds for every 60° C temperature increase; a decrease of 50 per cent per 50° C temperature increase would seem to be a good mean. If, for example, element life at 1000° C were arbitrarily taken at 100 per cent, then life at 1050° C would be 50 per cent, at 1100° C 25 per cent, etc. Therefore, care should be taken not to run the furnace any higher than necessary, and to avoid any conditions which may cause hot spots in the elements—such as laying a large piece of insulating material on the bottom element. In particular, care should be taken to prevent furnaces with input controls from "running away." These controls have a nasty habit of allowing the temperature to creep increasingly higher because temperature equilibrium conditions slowly change due to gradual heat saturation of the furnace insulation.

Temperature cycling will cause some decrease in element life, although there is some debate as to how much. It is probably best, therefore, to keep a furnace heated if it will be used again within an hour or so.

Many causes of element burn-out can be determined from examination of the element wire and, in some cases, the surrounding refractory. Perhaps the most frequent cause of burn-out is excessive temperature, possibly due to a forgotten input control, or maybe a hot spot from improper loading. The effects seen in this type of failure result from the tough oxide skin surrounding the wire; the core of the wire melts, but the molten metal is held in place by the skin. Often times the skin takes on a wrinkled appearance; sometimes the wire goes out-of-round; at the point of burn-out the skin breaks and the molten metal runs out.

Wires embedded in refractory cement will diffuse chromium into the surrounding material when operated at temperatures generally beyond those recommended. This gives a pink to red color to the refractory, most intense near the wire. Of course, this can only be noticed with light-colored refractory materials.

Burn-out from chemical attack is often evidenced by discoloration of the wire, and often by a warty appearance. For example, sulfur attack is caused by diffusion of sulfur along the grain boundaries of the wire, forming a nickel sulfide. This causes a typical warty surface, and often imparts a bright, silvery color to the otherwise dull oxide coating.

Chemical attack can sometimes come from unexpected sources. There is one event on record where it occurred (not to the element in this case but to other metallic objects in the furnace) and was traced to someone making toasted cheese sandwiches in the furnace during lunch hour.

Techniques

Individual users undoubtedly find their own little tricks to obtain more accurate results. The following outlines a few of these. Use of methods like this can often save the user many dollars by obtaining equal results with less expensive equipment.

The repeatability of a controller and thermocouple is much better than its accuracy; in fact,

the repeatability of less expensive controllers is closely equivalent to the very expensive units in most cases. Therefore, if one is interested primarily in getting certain results, he can vary the controller setting slightly until he gets these results; by noting the new setting of the controller he can then duplicate the process whenever desired.

If a potentiometer is available, one can run an error curve on the controller. Reference to this will give considerably more accurate temperature settings.

For those interested in only the most precise results, a selected platinum thermocouple (which is considerably more stable than a base metal thermocouple) can be used with a potentiometer to measure the temperature at the load. Overall accuracy of the order of one-half per cent or less may be so obtained..

There are many other things that could be said about electric furnace construction and operation. It has been attempted, however, to cover the most important points in this two-article series. For those interested in more detailed information, manufacturers of resistance wire, firebrick, insulation, and controllers can furnish pamphlets and brochures on the use of their products. In addition, there are a number of books on automatic control theory for those particularly interested in this aspect.

AUTOMATIC CONTROLLERS

Automatic controllers minimize controller supervision, releasing the operator for other duties. The set temperature is automatically maintained, eliminating variables introduced by the human element. All automatic controllers described below will turn power to the furnace off if the thermocouple circuit fails (oxidation of thermocouple, etc.).

COMPLETE AUTOMATIC ELECTRONIC CONTROLLERS

DUBUQUE II — A potentiometric non-indicating type controller designed for those uses within its 2% accuracy and 20 ampere load ratings. Absence of delicate moving parts makes this controller exceptionally rugged and provides long, trouble-free service. Control action is two position on-off. Simple connection change gives operation on 120, 208, or 240 volts, 60 cycles*. A complete packaged system for **$185.00***— Nothing else to buy. Scale range 2200°F/1200°C.

DUBUQUE III — Deluxe version of the DUBUQUE II controller. Includes cold junction compensation, proportioning, and 35 ampere load capacity as standard features. Available for 120 volts single phase and 208/240 volts single or three phase 60 cycles*. Control of 480 volt load is possible by special connection. Accuracy 1%. Scale ranges 800°F/425°C; 2000°F/1095C; and 2400°F/1300°C. A complete packaged system for **$230.00*** — Nothing else to buy.

PANEL MOUNTING AUTOMATIC ELECTRONIC CONTROLLERS

The following panel mounting controllers are designed for user assembled systems. The controllers may be mounted flat against a wall or recessed into a panel. In most cases a contactor and circuit breakers are also needed.

AMPLITROL — A potentiometric non-indicating controller — Prices: non-proportioning **$130.00***; proportioning **$140.00***. Scale ranges 800°F/425°C; 2000°F/1095°C; 2400°F/1300°C. Accuracy 1%. For 120/240 volts 60 cycles*.

CAPACITROL — A millivoltmeter type controller which continuously indicates temperature. Scale ranges: 1200°F/650°C; 2000°F/1095°C; 2500°F/1375°C. Prices: non-proportioning **$193.25;** proportioning **$203.25.** Accuracy 1%. For 120/208/240 volts 50/60 cycles.

THERMOLYNE CONTROL CABINETS

The *AMPLITROL* and *CAPACITROL* controller of your choice may be packaged in a Control Cabinet Assembly as a complete system, nothing else to buy** Maximum load 35 amperes, single or three phase. Designed to match all *THERMOLYNE* furnaces. Can also be used with most other makes and models within its ratings. Priced from $90.00 to $131.50** depending on the type of circuit and number of phases; add price of controller selected.

THERMOLYNE INPUT CONTROLLERS

Input controllers are preferred when initial cost is the primary consideration, and where the operator has time to supervise the control. Also suited for many non-critical uses, such as flask heater or hot plate control.

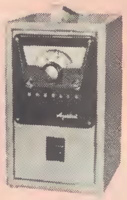
TEMCOMETER — A percentage timer type controller which holds input constant regardless of line voltage fluctuations. Contains a pyrometer to indicate temperature (not used in the control circuit). Scale ranges 2250°F/1200°C; 1600°F/870°C; 800°F/425°C. Prices: 2880 watts max. load, 120 or 240 volts **$72.50** 4080 watts at 120 volts or 7200 watts at 240 volts **$87.50.** For 50/60 cycles.

*Also available for 50 cycles, add **$10.00** to price shown.

**Base metal thermocouple included which may be cut to desired length. Units for platinum thermocouples do not include thermocouple.

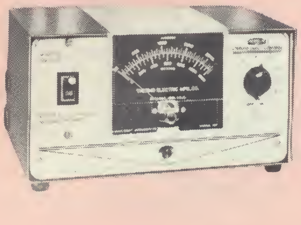
NOTE: For full descriptive material write for **THERMOLYNE** catalog 65.

DUBUQUE II



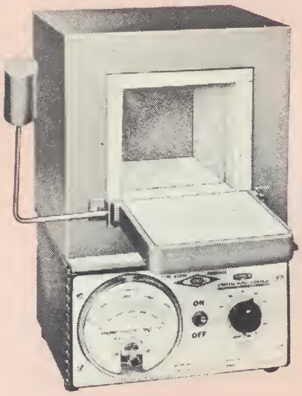
AMPLITROL (in cabinet)

CAPACITROL

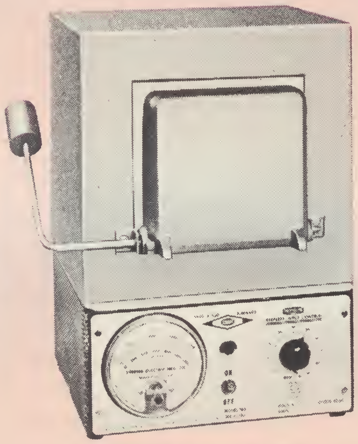


TEMCOMETER

THERMOLYNE
Electric Furnaces



TYPE 1300



TYPE 1400

Handy, portable bench type muffle furnaces—Plug in to ordinary outlets—Heats fast, ideal for quick jobs in lab, school, or shop—High quality materials and best workmanship throughout—Embedded heating element heats evenly—Large pyrometer indicates chamber temperature, makes supervision easy—Counterbalanced door forms work shelf.

Built-in manual percentage timer control holds input and operating temperatures within close limits—Compensates for voltage or ambient temperature changes—Infinitely stepless, user can select and hold desired temperature.

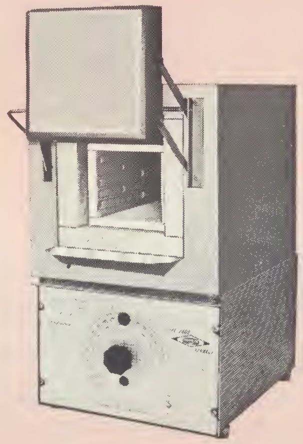
Large reserve power factor for useful heating—Fine performance on most jobs.

	ELECTRICAL DATA			CHAMBER SIZE			OVERALL SIZE			WEIGHT		
MODEL NO.	Volts	Amps	Watts	W	H	D	W*	H*	D	Net	Ship	PRICE
F-A1310M	240	4.4	1050	4	3¾	4½	8	12½	8½	16	23	$80.00
F-A1315M	120	8.8	1050	4	3¾	4½	8	12½	8½	16	23	80.00
F-A1318M	208	5.0	1050	4	3¾	4½	8	12½	8½	16	23	80.00
F-A1410M	240	6.3	1510	4⅞	4¼	6	10	14½	11	27	33	98.50
F-A1415M	120	12.6	1510	4⅞	4¼	6	10	14½	11	27	33	98.50
F-A1418M	208	7.2	1510	4⅞	4¼	6	10	14½	11	27	33	98.50

Customer's choice of many variables to suit his specific need—Automatic electronic control for accuracy, freedom from supervision; manual control for economy—Size, temperature range, and voltage options for wide selection freedom—One of these combinations ideal for most users, pick the one most advantageous for your work.

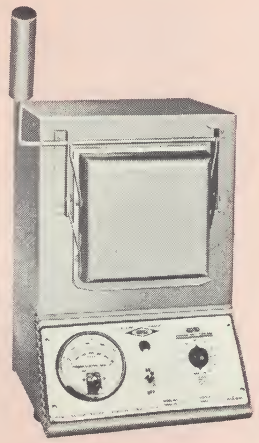
ELECTRONIC CONTROL—Automatic feed-back potentiometer type. User sets desired temperature on the dial, control heats furnace to set temperature and holds it within very close limits—Full power heats fast until setting is reached, then cycles as needed to hold—Minimum initial overshoot—Simple, sure control.

MANUAL CONTROL is percentage timer type—Electrothermally operated, thoroughly reliable—Automatically corrects for voltage or ambient temperature changes—Delivers set percentage of rated input, furnace stabilizes at a given temperature for each setting—Pyrometer makes required operator supervision easy.



AUTOMATIC CONTROL

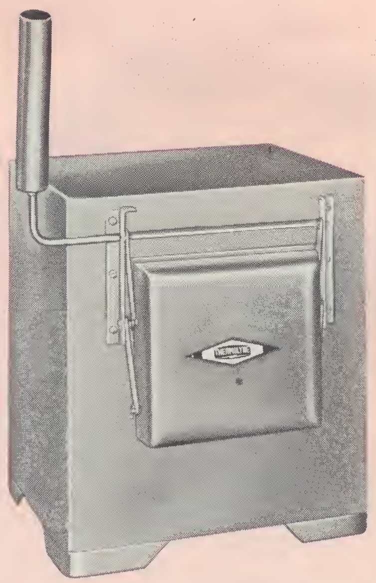
TYPE 2000



MANUAL CONTROL

TYPE 1500

	ELECTRICAL DATA			CHAMBER SIZE			OVERALL SIZE			OPERATING	WEIGHT		
MODEL NO.	Volts	Amps	Watts	W	H	D	W*	H*	D	TEMPERATURE	Net	Ship	PRICE
AUTOMATIC CONTROL													
F-A2020P	240	9.3	2240	4	3¾	9	11	18½	16	2000°F (1093°C)	60	70	$247.50
F-A2025P	120	18.6	2240	4	3¾	9	11	18½	16	2000°F (1093°C)	60	70	247.50
F-A2028P	208	10.8	2240	4	3¾	9	11	18½	16	2000°F (1093°C)	60	70	247.50
F-A2020P-1	240	9.3	2240	4	3¾	9	11	18½	16	2150°F (1177°C)	60	70	257.50
F-A2025P-1	120	18.6	2240	4	3¾	9	11	18½	16	2150°F (1177°C)	60	70	257.50
F-A2028P-1	208	10.8	2240	4	3¾	9	11	18½	16	2150°F (1177°C)	60	70	257.50
MANUAL CONTROL													
F-C1510M	240	6.3	1510	4	3¾	4½	11	16½	13½	2000°F (1093°C)	41	50	145.00
F-C1515M	120	12.6	1510	4	3¾	4½	11	16½	13½	2000°F (1093°C)	41	50	145.00
F-C1518M	208	7.2	1510	4	3¾	4½	11	16½	13½	2000°F (1093°C)	41	50	145.00
F-C1510M-1	240	6.3	1510	4	3¾	4½	11	16½	13½	2150°F (1177°C)	41	50	155.00
F-C1515M-1	120	12.6	1510	4	3¾	4½	11	16½	13½	2150°F (1177°C)	41	50	155.00
F-C1518M-1	208	7.2	1510	4	3¾	4½	11	16½	13½	2150°F (1177°C)	41	50	155.00
F-C1520M	240	9.3	2240	4	3¾	9	11	16½	18	2000°F (1093°C)	55	67	155.00
F-C1525M	120	18.6	2240	4	3¾	9	11	16½	18	2000°F (1093°C)	55	67	155.00
F-C1528M	208	10.8	2240	4	3¾	9	11	16½	18	2000°F (1093°C)	55	67	155.00
F-C1520M-1	240	9.3	2240	4	3¾	9	11	16½	18	2150°F (1177°C)	55	67	165.00
F-C1525M-1	120	18.6	2240	4	3¾	9	11	16½	18	2150°F (1177°C)	55	67	165.00
F-C1528M-1	208	10.8	2240	4	3¾	9	11	16½	18	2150°F (1177°C)	55	67	165.00

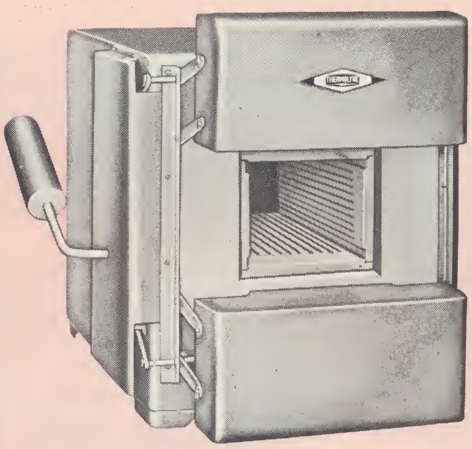


TYPE 1600

Larger bench type laboratory furnaces—Ruggedly built for long life, low cost operation—Embedded heating elementts for even heat, protection of elements — Two sizes, two temperature ranges in each type—Selection of controls (sold separately, see page 9) to suit varying conditions—Patented door suspensions keep hot side away from operator.

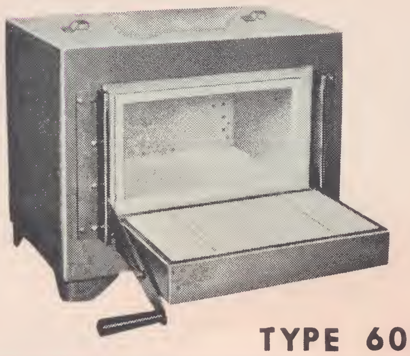
Type 1700 has optional shelf, doubles capacity for small parts—Sectional door provides access to chamber with minimum heat loss.

For higher temperature operation (2150°F/1177°C) add "-1" to model number shown in table and $15.00 to price of type 1600, $22.00 to price of 1700.



TYPE 1700

SPECIFICATIONS											PRICE
Furnace Model Number	ELECTRICAL DATA			CHAMBER SIZE			WEIGHT		Maximum Operating Temperature	Thermo-couple	Furnace Only
	Volts	Amps	Watts	H	W	D	Net	Ship.			
F-A1620	240	12.5	3000	4⅞	5½	9	120	140	2000°F (1093°C)	C/A	**$157.50**
F-A1625	120	25.0	3000	4⅞	5½	9	120	140	2000°F (1093°C)	C/A	**157.50**
F-A1628	208	14.4	3000	4⅞	5½	9	120	140	2000°F (1093°C)	C/A	**157.50**
F-A1630	240	17.0	4100	4⅞	5½	13½	145	170	2000°F (1093°C)	C/A	**177.50**
F-A1635	120	34.0	4100	4⅞	5½	13½	145	170	2000°F (1093°C)	C/A	**177.50**
F-A1638	208	19.7	4100	4⅞	5½	13½	145	170	2000°F (1093°C)	C/A	**177.50**
F-A1730	240	24.0	5800	8½	9½	13½	402	470	2000°F (1093°C)	C/A	**310.00**
F-A1738	208	27.7	5800	8½	9½	13½	402	470	2000°F (1093°C)	C/A	**310.00**
F-A1740	240	33.0	7900	8½	9½	18	485	535	2000°F (1093°C)	C/A	**360.00**
F-A1748	208	33.0	6900	8½	9½	18	485	535	2000°F (1093°C)	C/A	**360.00**



TYPE 6000

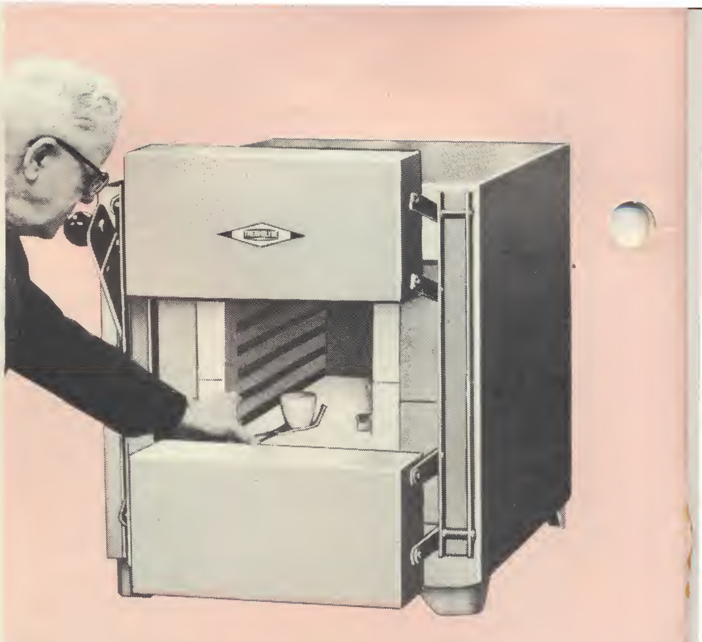
Radiant heat from all six sides gives exceptionally uniform temperature over entire chamber—Ideal for tempering and drawing heat treated parts—Large chamber with wide door handles big loads—Self-latching door, operated with one hand, forms handy work shelf—Selection of controls (sold separately, see page 9) suit furnace to wide variety of work—Embedded heating elements easily replaced by user—Chamber is vented to allow combustion products to escape—Designed for close control medical work (PBI), ideal for similar critical temperature heating operations.

SPECIFICATIONS											PRICE
Furnace Model Number	ELECTRICAL DATA			CHAMBER SIZE			WEIGHT		Maximum Operating Temperature	Thermo-couple	Furnace Only
	Volts	Amps	Watts	H	W	D	Net	Ship.			
F-6020	240	17.0	4080	6⅞	12¾	10	150	185	1900°F (1038°C)	C/A	**$310.00**
F-6025	120	34.0	4080	6⅞	12¾	10	150	185	1900°F (1038°C)	C/A	**310.00**
F-6028	208	19.6	4080	6⅞	12¾	10	150	185	1900°F (1038°C)	C/A	**310.00**

A large bench type furnace for high volume laboratory work or production heating—Built to rigid performance specifications, husky and efficient—High grade alloy heating elements, heavy gauge for long life—Elements supported in special chemically bonded refractory forms—refractory developed for this specific purpose—Close sealing sectional door permits access to chamber with minimum heat loss.

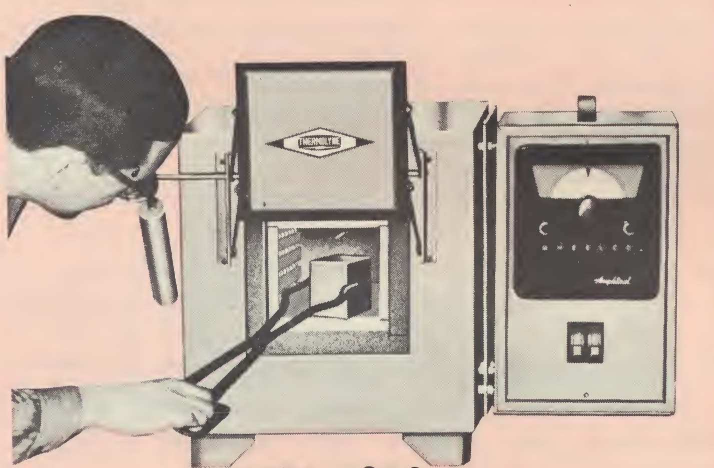
Models for most common domestic and foreign voltages, single or three phase—Two temperature ranges for varied uses—Selection of controls (sold separately, see page 9) permit user to choose the best one for him—(For operation near top temperatures we recommend proportioning controls.) Safety switch shuts off power when door is opened.

High temperature models (designated by "-1" in the table) will handle most high speed steel heat treating.



TYPE 1800

SPECIFICATIONS											PRICE
Furnace Model Number	ELECTRICAL DATA				CHAMBER SIZE			WEIGHT		Maximum Operating Temperature	Thermo-couple	Furnace Only
	Volts	Phase	Amps	Watts	H	W	D	Net	Ship.			
F-1850	240	1	52.0	12,500	9½	10	22	695	790	2000°F (1093°C)	C/A	**$685.00**
F-1850-1*	240	1	52.0	12,500	9½	10	22	695	790	2300°F (1260°C)	Pt/Pt 13% Rho	**730.00**
3F-1850	240	3	29.7	12,400	9½	10	22	695	790	2000°F (1093°C)	C/A	**700.00**
3F-1850-1*	240	3	30.2	12,600	9½	10	22	695	790	2300°F (1260°C)	Pt/Pt 13% Rho	**745.00**
3F-1852	400-420	3	16.4	11,900	10⅜	10⅞	22	695	790	2000°F (1093°C)	C/A	**750.00**
3F-1852-1*	400-420	3	16.4	11,900	10⅜	10⅞	22	695	790	2300°F (1260°C)	Pt/Pt 13% Rho	**795.00**
3F-1856	480	3	17.0	14,100	10⅜	10⅞	22	695	790	2000°F (1093°C)	C/A	**750.00**
3F-1856-1*	480	3	17.0	14,100	10⅜	10⅞	22	695	790	2300°F (1260°C)	Pt/Pt 13% Rho	**795.00**
3F-1858	208	3	31.2	11,300	9½	10	22	695	790	2000°F (1093°C)	C/A	**700.00**
3F-1858-1*	208	3	31.2	11,300	9½	10	22	695	790	2300°F (1260°C)	Pt/Pt 13% Rho	**745.00**



TYPE 1900

A small high temperature bench furnace with a deep chamber for heating long parts, or several smaller parts in a uniform temperature zone—High grade elements, heavy gauge for long life—Elements supported in special chemically bonded refractory forms, refractory developed for this specific purpose—Multiple layers of high grade insulation, firebrick backed up with best materials for minimum heat loss—Steel case, finished in heat resistant enamel—Patented safety door swings up and out, keeping hot side away from operator—Safety switch shuts off power when door is opened.

SPECIFICATIONS										PRICE
Furnace Model Number	ELECTRICAL DATA			CHAMBER SIZE			WEIGHT		Maximum Operating Temperature	Thermo-couple	Furnace Only
	Volts	Amps	Watts	H	W	D	Net	Ship.			
F-1930	240	17.0	4100	4 3/16	4 7/16	13¼	177	200	2000°F (1093°C)	C/A	**$215.00**
F-1930-1*	240	17.0	4100	4 3/16	4 7/16	13¼	177	200	2300°F (1260°C)	Pt/Pt 13% Rho	**235.00**
F-1935	120	34.0	4100	4 3/16	4 7/16	13¼	177	200	2000°F (1093°C)	C/A	**215.00**
F-1935-1*	120	34.0	4100	4 3/16	4 7/16	13¼	177	200	2300°F (1260°C)	Pt/Pt 13% Rho	**235.00**
F-1938	208	19.3	4000	4 3/16	4 7/16	13¼	177	200	2000°F (1093°C)	C/A	**215.00**
F-1938-1*	208	19.3	4000	4 3/16	4 7/16	13¼	177	200	2300°F (1260°C)	Pt/Pt 13% Rho	**235.00**